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DIVISION OF AGRONOMY

A Chemical and Microbiological Study of Lufkin Fine Sandy Loam in Relation to Productiveness

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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In a study of some of the factors of productiveness of Lufkin fine sandy loam soil at College Station, Texas, in 1925, 1926, and 1927, it was found that the nitrifying power of the soil was positively and significantly correlated with the yields of cotton and corn. The nitrifying capacity of the soil was a better index of the crop-producing power of the soil than the total nitrogen, the total phosphoric acid, or the active phosphoric acid of the soil.

The addition of nitrogenous materials, cottonseed meal and manure, and of phosphoric acid, as superphosphate and ground rock phosphate, stimulated the nitrifying power of the soil and increased the production of nitrates in field soil. Under conditions in the laboratory the addition of lime increased the power of the soil to produce nitrates, although this increased nitrifying power was not more significantly correlated with the yields of cotton and corn than was the nitrifying power of the soil without lime. Seasonal conditions did not influence the nitrifying power of the soil under conditions in the laboratory, as indicated by analyses of samples taken at monthly intervals during the growing season.

The continuous growing of cotton and of corn decreased the production of nitrates in field soil. The growing of corn on the same land every year also had a tendency to weaken the nitrifying power of the soil, a fact which apparently explains why the yield of corn is reduced more by continuous cropping than is the yield of cotton.

The accumulation of nitrates in the soil gradually increased as the season advanced, reaching a peak in July in the soil under cotton and in August in the soil under corn, and decreased thereafter.

The use of the statistical method appears to be a promising means of interpreting soil fertility data and increasing the reliability of conclusions drawn from such data.

CONTENTS

A CHEMICAL AND MICROBIOLOGICAL STUDY OF LUFKIN FINE SANDY LOAM IN RELATION TO PRODUCTIVENESS

E. B. REYNOLDS

Field experiments with fertilizers conducted by the Division of Agronomy, Texas Agricultural Experiment Station, on Lufkin fine sandy loam soil at College Station, Texas, from 1914 to 1921 showed that the soil does not respond readily to the fertilizer treatments used, as indicated by the yields of crops grown. This fact indicated that factors other than plant nutrients were the cause of this lack of response. The fact also suggested that a study of the chemical and bacteriological activities of the soil might show the relation of these activities to the fertility of the soil, since investigations in various parts of the world have shown that certain microbiological activities in the soil as determined by laboratory tests are indicative of the crop-producing power of the soil or the relative crop-producing power of two or more soils. Brown (7, 8) in Iowa showed that the nitrifying power and certain other bacteriological processes in the soil were correlated with the crop yields secured. Burgess (9) reported that "Nitrification (soil culture method) is by far the most accurate biological soil test yet perfected for predicting probable fertility. In fact, it is probably the best single test of any description yet developed for ascertaining the comparative crop-producing power of arable soils."

Waksman (22) and a number of other workers have reported similar results. It has been found that different crops growing on the soil have a different effect on the bacterial activities of the soil.

In view of the above facts it was thought desirable to make a study of the chemical and microbiological activities in the Lufkin fine sandy loam to determine if possible the relation of these activities to the crop-producing power of the soil under specific fertilizer treatments. Accordingly, an experiment was planned in 1921 to obtain information along this line. The work, unfortunately, was delayed until the summer of 1925, when it was begun actively. Results were obtained during three crop seasons, 1925, 1926, and 1927, and the data secured are reported in this Bulletin.

REVIEW OF LITERATURE

Microbiological processes in the soil have been studied by investigators for many years. Much work along this line has been done since 1877, when Schloesing and Muntz showed that nitrification is a biological process. The effects of various factors, such as temperature, moisture, air, organic matter, reaction of culture medium, various chemical substances, fertilizers, plants, and different cropping systems on the various microbiological processes, have received considerable attention. Nitrification is the chief microbiological process considered in the work reported in this paper. It is not desired to review all of the literature dealing with the study of nitrification, since much of it has no direct bearing on this work. It is desirable, however, to consider the more important contributions pertaining to phases of the subject that are involved in this investigation. The references given include those setting forth the effect of fertilizers, manure, cropping systems, and seasonal conditions on nitrification.

Warington (23) at Rothamsted as early as 1878 showed that crops and manurial treatment have an effect on the accumulation of nitrates in soil. On Broadbalk Field, devoted to continuous wheat, the soil which received 14 tons of barnyard manure per acre annually for 38 years, contained about three times as much nitrate nitrogen as the unmanured soil. Similar results were obtained on the soil growing barley.

Brown (5) in 1911 made a bacteriological study of field soils in Iowa. The study was made on soil in eight different cropping systems including continuous corn; continuous clover; a two-year rotation of corn and oats; two-year rotations of corn and oats in which clover, cowpeas, and rye were plowed under as green manure after oats; and a three-year rotation of corn, oats, and clover. The soil on the plats in the rotations had greater nitrifying and nitrogen-fixing powers than the soil on the plats devoted to continuous corn or clover. The use of green manures did not increase the nitrifying power of the soil. The nitrifying power of the soil was correlated with the yield of corn. Later Brown (7, 8) showed there was such a close relation between the bacterial activities studied and crop yields that a study of "bacterial activities in the laboratory may indicate quite accurately the crop-producing power of a soil or, at least, the relative crop-producing power of several soils."

Brown (6) also studied the effect of manure on the soil in a four-year rotation of corn, corn, oats, and clover. Manure was applied at the rates of 8, 12, 16, and 20 tons per acre. The applications of 12 and 16 tons per acre brought about the greatest nitrifying power in the soil and produced the largest yields of corn. He found that there was a close relationship between the bacterial activities studied and the crop-producing power of the soil.

Lyon and Bizzell (15) made studies on the relation of certain higher plants to the formation of nitrates in soil on which maize, timothy, millet, and potatoes were grown. During the most active growing period of maize, nitrates were frequently higher in the soil under maize than in a cultivated soil that bore no crop. The soil under a mixture of maize and millet contained larger quantities of nitrates than the soil under the millet alone, although the crop yields were about the same in both cases.

Russell (21) at Rothamsted observed that land cropped to wheat and barley contained smaller amounts of nitrates than fallow soil.

White (25) noted that crops influence the accumulation of nitrates in the soil. Corn-stubble land contained 24.91 parts per million of nitrates; soil under clover sod, 13.14 parts per million; soil under clover and timothy, 9.23 parts per million; and soil under winter wheat, 36.47 parts per million.

Allen (3) found a close relationship between nitrification and crop production on plats devoted to continuous culture of crops, but there was no consistent relation between nitrification and crop production on the manured plats in a three-year rotation of corn, wheat, and clover.

Gainey and Gibbs (11) in Missouri determined the number of organisms, the ammonifying power, and the nitrifying power of a soil which received manure, chemicals, and no treatment under (a) six-year rotation, (b) continuous corn, (c) continuous wheat, and (d) continuous timothy. The untreated soils under continuous corn and wheat had rather low nitrifying powers, which, however, were increased by commercial fertilizers.

Albrecht (1) studied the effect of crops and cultivation on nitrate production. He found that a reduction in the amount of nitrates occurred when the crop was making the most rapid growth. With corn, nitrates accumulated until late in June, but decreased thereafter. No significant accumulation of nitrates ever occurred in oats and timothy sod, but a slight increase occurred after the crops were harvested. Albrecht (2) also determined the effect of long-continued treatments on the bacterial activities of soil, especially under continuous oats and continuous wheat. Manure increased the accumulation of nitrates in the soil and the addition of lime increased the nitrate content still further.

Prescott (20) in Egypt observed a relatively large accumulation of nitrates in a typical Nile alluvial soil under cotton, but no such accumulation occurred under wheat or maize.

Martin and Massey (17) also reported an accumulation of nitrates in soil under a growing crop of cotton. Yields of wheat on unmanured soils were better where the initial nitrate content was high than where it was slow.

Whiting and Schoonover (26) made a study of nitrate production in field soils in Illinois over a period of four years. The work included several cropping systems and fertilizer treatments. The treatments consisted of crop residues, manure, green manure, limestone, and phosphorus alone and in combination. The treatment of lime, manure, and phosphorus brought about the greatest production of nitrates and the largest yield of corn two of the three years in which yields were reported. The soil under the rotation of potatoes, corn, soybeans, and alfalfa (7 years) contained more nitrates than the soil under the other rotations.

Hall (12) in South Africa reported that land on which maize followed cowpeas that had been cut for hay contained more nitrates than land on which maize followed maize.

Baldwin, Nichter, and Lindsey (4) found that the rotation of crops on soils in Indiana increased the nitrifying power of the soil. Soil cropped continuously to wheat and to corn exhibited a lower nitrifying power than soil in rotations of (a) corn, wheat, clover, and timothy; (b) corn, oats, wheat, clover, and timothy; (c) corn and wheat; and (d) corn, oats, and wheat.

Welton and Morris (24) in Ohio made a study of the yields of wheat following potatoes and the relation of the nitrate content of the soil to the yield of wheat. The work embraced one-, two-, three-, four-, and five-year rotations in which wheat followed corn, soybeans, oats, clover, potatoes, and wheat. In general they found that the yield of wheat was somewhat higher after potatoes than after other crops.

In 1922 and 1923 Murphy (18) in Oklahoma determined the nitrate content and nitrifying power of manured and unmanured soil on which wheat had been grown continuously since 1893. Manure had been applied at the average rate of 4 tons per acre for the last 26 years. The manured soil had a greater nitrifying power and contained about twice as much nitrate nitrogen as the unmanured soil during the dormant period of the wheat.

The relation of the nitrate content of soil to the yield of wheat in seven different rotations of crops was studied by Karraker (14). The largest yield of wheat and the highest average amount of nitrates were obtained in the three-year rotation of tobacco, wheat, and clover during the five seasons. Karraker also made a study of the effect of crops on the production of nitrates in the soil during the season following the growth of the crop. Tobacco, hemp, oats, soybeans, and corn were grown in small plats. The largest amount of nitrates was found in the soil that grew soybeans and the smallest amount in the soil that grew hemp. The amount of nitrates increased in the soil as the season advanced from April to August.

METHOD OF CONDUCTING THE EXPERIMENT

These studies were made on the soil under a four-year rotation of cotton, cowpeas, corn, and oats, and under continuous cotton and continous corn. The soil devoted to oats, however, was not included in the study because the oats occupied the land during the fall and winter and it was desired to make the studies on soil under growing crops during the summer months. The soil is classified as Lufkin fine sandy loam. The surface is gray to ashy gray in color; the subsoil is a gray or mottled grayish and yellowish plastic clay. The topography of a typical Lufkin soil may be either flat, gently undulating, or slightly rolling, and this together with the somewhat impervious nature of the subsoil, results in poor surface and internal drainage. The soil used in these studies, however, has fairly good surface drainage, but the internal drainage is typical of the series. The Lufkin soils in general are low in organic matter and nitrogen. In the virgin state these soils, in Texas, are forested, the heavier types mainly with post oak, and the more sandy types with pine and mixed hardwood.

These studies in soil fertility were made by taking samples of soil at monthly intervals during the growing season from plats receiving various fertilizer treatments and analyzing them to determine the nitrate content, the nitrifying power, total nitrogen, total phosphoric acid, and the active phosphoric acid. The data obtained from these analyses were analyzed by the statistical method to show the relationship of the several factors studied to the fertility of the soil as measured by the yield of crops.

Fertilizer Treatments

The following treatments were used in these studies:

Plat No.	Treatment per acre
1	200 lbs. superphosphate 100 lbs. cottonseed meal
2	Crop residues removed
3	No treatment—check
4	200 lbs. superphosphate
5	4 tons manure
6	No treatment—check
7	200 lbs. superphosphate 4 tons manure
8	107 lbs. rock phosphate*
9	107 lbs. rock phosphate* 4 tons manure
10	No treatment—check

These treatments were applied to each crop every year.

Time and Method of Taking Samples of Soil

Samples of soil were collected in May, June, July, August, and September, of 1925, 1926, and 1927. The samples were taken to a depth of seven inches at nine different places on each plat and a composite sample was obtained by thoroughly mixing these samples.

Microbiological Studies

The microbiological studies included the determination of the amounts of nitrates in the soil under the growing crops and of the nitrifying power of the soil. The nitrifying power of the soil, that is, nitrification in the soil under laboratory conditions, was determined according to the soil culture method of Brown (5), using ammonium sulphate. In 1927, the study included the nitrification of ammonium sulphate in the presence of the theoretical quantity of calcium carbonate required to neutralize the acids formed by the complete oxidation of the ammonium sulphate to nitric acid and sulphuric acid, as suggested by Waksman (22). In 1925 and 1926, the determinations of nitrates in the soil and of the nitrifying power of the soil were made on moist

*The rock phosphate contained the same amount of phosphoric acid as the 200 pounds of superphosphate.

samples as obtained from the field, while in 1927 the determinations were made on samples that previously had been air dried. In determining the nitrifying power of the soil enough tap water was added to the moist or air-dry soil to bring the moisture content up to 60 per per cent of the water-holding capacity of the soil. The quantity of nitrates is reported as nitrate nitrogen in parts per million of water-free soil. The nitrifying power of the soil is stated as milligrams of nitrate nitrogen in 100 grams of water-free soil. The nitrates in both cases were determined by the method of the Association of Official Agricultural Chemists (19)—except in 1927, when Harper's method was used (13).

Chemical Studies

The chemical studies included determinations of (a) total nitrogen, (b) active phosphoric acid, (c) total phosphoric acid, and (d) hydrogen ion concentration of the soil. The active phosphoric acid was determined by Fraps' method (10) and the total phosphoric acid according to the method of the Association of Official Agricultural Chemists (19). The hydrogen ion concentration of the samples collected in 1927 was determined by the colorimetric method.

MICROBIOLOGICAL STUDIES

The microbiological studies included the effect of crops, season, and fertilizer treatments of the soil on the accumulation of nitrates and on the nitrifying capacity of the soil. These data were rather voluminous and it was deemed advisable to condense them into average tables for convenience of discussion. For instance, to ascertain the effect of crops on the nitrate content of the soil, the amount of nitrates under each crop at the several dates of sampling was averaged, and the averages thus obtained for the several crops were compared directly. In a like manner the seasonal effects on the accumulation of nitrates were shown by averaging the amount of nitrates in the soil under all crops for each date of sampling.

Effect of Crops on Accumulation of Nitrates in Soil

The effect of cotton, corn, and cowpeas on the accumulation of nitrates in the soil during the growing seasons of 1925, 1926, and 1927 is shown in Tables 1, 2, and 3. The average nitrate content of the soil for any treatment is found by averaging the quantity of nitrates in the soil under each crop receiving that treatment, at the five dates of sampling. For example, during the growing season of 1925 the average nitrate content of the soil on Plat 1 (200 pounds of superphosphate and 100 pounds of cottonseed meal per acre) under continuous corn was only .71 parts per million, which is the arithmetic average of the nitrate content in parts per million of dry soil at the five dates of sampling, May 26, June 26, July 25, August 28, and September 30, 1925.

Season of 1925: Nitrates were present in rather small amounts in the soil under the growing crops (Table 1). This low accumulation of nitrates is undoubtedly due to the unusually dry season. The soil was practically air dry at the first sampling (May 26) and at the third sampling (July 25) and the moisture content was low at the other samplings. Yet as an average of all the treatments, the soil on which the rotated cotton was growing contained more than twice as much nitrates as the soil under either continuous cotton or continuous corn. The soil under crops grown in rotation contained relatively much larger quantities of nitrates than the soil under continuous crops, although the absolute amounts were small. In general the soil receiving manure contained relatively larger amounts of nitrates than the other treatments. The soil on which all crop residues have been removed since 1914 contained the smallest amount of nitrates. While there was some observable effect of crops on the accumulation of nitrates in the soil, it may be stated that the unprecedented dry season of 1925 prevented a typical expression of the effect that crops may have on the accumulation of nitrates in the soil, as will be indicated by comparing the data obtained in 1925 with the data obtained in 1926.

Season of 1926: The soil under crops grown in rotation (cotton, corn, and cowpeas) contained significantly larger amounts of nitrates than the soil under continuous cotton or continuous corn (Table 2). The soil on which rotated corn was growing contained, as an average for the season, 13.18 parts per million of nitrates in dry soil, as compared with 8.58 parts per million for the soil under continuous corn. The results are in agreement with those of Brown (5) in Iowa. The soil under rotated corn apparently showed less variation in nitrate content among the different treatments than the soil bearing the other crops. The largest amount of nitrates (17.45 parts per million) occurred on the plats receiving rock phosphate and manure under rotated corn. This treatment also produced the largest amount of nitrates (17.43 parts per million) in the soil under cowpeas. The treatment of manure and superphosphate brought about the greatest production of nitrates in the soil under rotated and continuous cotton.

Season of 1927: There were no great differences in the quantity of nitrates found in the soil under the different crops during the season of 1927. The soil under continuous corn, however, in the case of every treatment, contained smaller amounts of nitrates than the soil under other crops (Table 3). The soil under rotated cotton and under rotated corn contained on the average equal amounts of nitrates during the season.

Considering the results for the three years of the experiment, it may be stated that the crops and cropping systems used affected the accumulation of nitrates in the soil. The soil under rotated cotton contained the largest amount of nitrates during the crop seasons of 1925 and 1927, but the soil under rotated corn contained the largest average

Table 1.—Average amount of nitrate nitrogen in parts per million of dry soil under different crops, May to September, inclusive, 1925

Plat No.	Treatment per acre	Continuous corn	Rotated corn	Continuous cotton	Rotated cotton	Rotated cowpeas	Average
		P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	0.71	1.02	0.59	1.40	1.36	1.02
2	Crop residues removed	0.47	0.99	0.47	1.19	0.78	0.78
3	No treatment—check	0.55	1.33	0.43	1.64	0.83	0.96
4	200 lbs. superphosphate	0.49	1.14	0.79	1.64	0.86	0.98
5	4 tons manure	0.69	2.17	0.96	1.90	1.35	1.41
6	No treatment—check	0.48	0.99	0.50	1.10	0.87	0.79
7	200 lbs. superphosphate, 4 tons manure	0.92	1.34	1.01	2.06	1.45	1.36
8	107 lbs. rock phosphate	1.01	1.07	0.82	1.87	1.13	1.18
9	107 lbs. rock phosphate, 4 tons manure	1.10	0.88	0.92	3.26	2.45	1.73
10	No treatment—check	0.97	0.79	1.02	2.41	1.73	1.38
	Average	0.74	1.17	0.75	1.85	1.28	....

Table 2.—Average amount of nitrate nitrogen in parts per million of dry soil under different crops, May to September, inclusive, 1926

Plat No.	Treatment per acre	Continuous corn	Rotated corn	Continuous cotton	Rotated cotton	Rotated cowpeas	Average
		P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	6.29	10.19	11.13	9.76	12.22	9.92
2	Crop residues removed	5.82	10.74	5.95	8.94	6.12	7.51
3	No treatment—check	7.04	11.50	5.89	10.64	7.04	8.42
4	200 lbs. superphosphate	7.03	12.05	7.62	8.81	12.89	9.68
5	4 tons manure	9.22	14.35	10.46	13.24	12.80	12.01
6	No treatment—check	6.09	12.96	10.26	11.16	5.52	9.20
7	200 lbs. superphosphate, 4 tons manure	10.50	15.38	15.84	14.57	15.31	14.32
8	107 lbs. rock phosphate	10.89	13.64	10.68	9.20	12.96	11.47
9	107 lbs. rock phosphate, 4 tons manure	12.02	17.45	11.07	11.16	17.43	13.83
10	No treatment—check	10.90	13.55	11.51	11.78	12.55	12.06
	Average	8.58	13.18	10.04	10.93	11.48	....

amount for the three years, which was due mainly to the large amounts in the soil in 1926 after the corn had ceased taking up nitrates. The soil under continuous cotton and under continuous corn contained smaller amounts of nitrates than the soil under a rotation, indicating that the continuous growing of one crop on the soil has a depressing effect on the accumulation of nitrates.

Correlation Between Amount of Nitrates and Yield of Cotton: A statistical analysis of the data obtained in the experiment was made, the results of which are discussed later, but a discussion of the correlation existing between the quantity of nitrates in the soil and the yield of cotton and corn is pertinent here. In 1926 the correlation coefficient between the average amount of nitrates during the season and the yield of continuous cotton was .552 ±.155; while for rotated cotton the correlation coefficient was .491 ±.162, both of which are significant (Table 13). In 1927 the correlation coefficient between the amount of nitrates and yield of continuous cotton was .700 ±.109 and of rotated cotton .389 ±.181, the former being significant. These results indicate that the yield of cotton has a tendency to be closely associated with the amount of nitrates in the soil.

Correlation Between Amount of Nitrates and Yield of Corn: There appeared to be no correlation between the yield of continuous corn and the amount of nitrates in the soil during the crop seasons of 1926 and 1927, as indicated in Table 14. On the other hand, there was a significant negative correlation between the yield of rotated corn and the amount of nitrates in the soil, the coefficient of correlation being —.781 ±.083 in 1927.

Since there was significant positive correlation between the quantity of nitrates in the soil and the yield of both rotated and continuous cotton during the two years and since there was negative correlation between the amount of nitrates and the yield of rotated corn and little or no correlation in the case of continuous corn, it is concluded that the yield of cotton was more closely correlated with the quantity of nitrates in the soil than was the yield of corn. This is probably due to the fact that cotton puts on fruit over a rather long period and used nitrates during most of the period, while corn is a determinate type of plant, setting its fruit during a short period of time, and perhaps did not take up nitrates from the soil after the sampling in July. The results indicate that under the particular conditions cotton was a better "soil indicator" than corn.

Effect of Season on Accumulation of Nitrates

The amount of nitrates in the soil at each date of sampling in 1925, 1926, and 1927 is given in Tables 4, 5, and 6. The quantity of nitrates for each date is the average amount found in the soil under the five crops. For example, the soil on the plat receiving 200 pounds of superphosphate and 100 pounds of cottonseed meal per acre contained

Table 3.—Average amount of nitrate nitrogen in parts per million of dry soil under different crops, May to September, inclusive, 1927

Plat No.	Treatment per acre	Continuous corn	Rotated corn	Continuous cotton	Rotated cotton	Rotated cowpeas	Average
		P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	200 lbs. superphosphate, 100 lbs. cottonseed meal...	2.83	4.12	4.83	5.99	4.98	4.55
2	Crop residues removed........................	2.81	4.51	3.83	4.54	3.78	3.89
3	No treatment—check..........................	2.87	4.41	4.41	5.17	3.87	4.15
4	200 lbs. superphosphate.......................	3.34	4.33	4.28	5.97	4.19	4.42
5	4 tons manure................................	3.91	5.07	5.29	7.44	6.17	5.58
6	No treatment—check..........................	3.07	4.76	5.20	6.47	4.55	4.81
7	200 lbs. superphosphate, 4 tons manure...........	3.75	6.48	6.13	7.46	5.91	5.95
8	107 lbs. rock phosphate.......................	3.49	5.30	5.94	6.47	5.29	5.30
9	107 lbs. rock phosphate, 4 tons manure............	4.29	12.88	5.28	6.71	6.82	7.20
10	No treatment—check..........................	4.21	11.42	5.71	7.28	4.93	6.71
	Average................................	3.46	6.33	5.09	6.35	5.05	....

Table 4.—Amount of nitrate nitrogen in parts per million of dry soil at different dates in 1925.

Plat No.	Treatment per acre	May 26	June 26	July 25	August 28	Sept. 30	Average
		P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	200 lbs. superphosphate, 100 lbs. cottonseed meal...	1.37	1.17	1.01	0.68	0.83	1.01
2	Crop residues removed........................	1.16	1.01	0.81	0.40	0.52	0.78
3	No treatment—check..........................	1.59	0.94	1.19	0.44	0.63	0.96
4	200 lbs. superphosphate.......................	1.57	1.28	0.99	0.55	0.53	0.98
5	4 tons manure................................	2.37	1.43	1.95	0.61	0.72	1.42
6	No treatment—check..........................	1.27	0.74	0.88	0.52	0.53	0.79
7	200 lbs. superphosphate, 4 tons manure...........	1.70	1.40	1.65	0.78	1.25	1.36
8	107 lbs. rock phosphate.......................	1.94	1.09	1.19	0.89	0.80	1.18
9	107 lbs. rock phosphate, 4 tons manure............	1.94	1.94	2.14	1.41	1.20	1.73
10	No treatment—check..........................	2.02	1.64	1.52	0.83	0.91	1.38
	Average................................	1.69	1.26	1.33	0.71	0.79	....

4.62 parts per million of nitrates on May 17, 1926, which was the average amount of nitrates in the soil receiving the treatment on continuous cotton, rotated cotton, continuous corn, rotated corn, and rotated cowpeas on that date. It should be pointed out that averaging the figures in this manner may mask the effects of the individual crops. Since the same crops are present in each case, the average does not introduce a variable although it may mask or obscure the influence of the individual crops, as mentioned above.

Season of 1925: During the growing season of 1925 the amount of nitrates was unusually small at every date of sampling (Table 4). In a general way the accumulation of nitrates in the soil did not vary much during the season. The samples collected on May 26 had a greater concentration of nitrates than the samples taken on the other dates. The lack of moisture, however, was the controlling factor in the production and accumulation of nitrates at all times during the season. Even though nitrates were present in such small amounts, the soil on the plats which received manure contained relatively larger amounts of nitrates than the soil which received other treatments. The plats on which the crop residues were removed had the smallest amount of nitrates.

Season of 1926: In 1926 conditions were much more favorable for the accumulation of nitrates in the soil than they were in 1925. The average quantity of nitrates in the soil increased from 5.51 parts per million in May to 16.44 parts per million in August and decreased thereafter (Table 5). A nitrate content of 16.44 parts per million apparently is a high concentration of nitrates in Lufkin fine sandy loam. The soil treated with manure had larger quantities of nitrates at each date of sampling, as a rule, than the soil receiving other treatments. The soil on which the crop residues were removed contained, on the average, less nitrate nitrogen than the soil receiving other treatments.

Season of 1927: The average quantity of nitrates in the soil as determined from the average of all crops and treatments, decreased from May to July and August and increased thereafter (Table 6). The soil which received manure and rock phosphate contained the largest, and the soil with the crop residues removed the smallest amount of nitrates during the season. The soil from which the residues were removed contained the smallest average amount of nitrates during each of the three years. The conditions in 1927 were not as favorable for the production and accumulation of nitrates in the soil as were the conditions in 1926, as may be seen by comparing the results in Tables 5 and 6.

Nitrifying Power of Soil

Soils from the different plats were studied from the standpoint of their ability to nitrify ammonium sulphate according to the method

Table 5.—Amount of nitrate nitrogen in parts per million of dry soil at different dates in 1926

Plat No.	Treatment per acre	May 17	June 16	July 17	August 17	Sept. 17	Average
		P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	4.62	5.78	12.96	16.91	9.26	9.91
2	Crop residues removed	4.66	5.65	7.41	11.82	8.01	7.51
3	No treatment—check	4.98	6.18	9.26	13.63	8.05	8.42
4	200 lbs. superphosphate	5.45	6.92	12.33	15.14	8.97	9.76
5	4 tons manure	5.82	9.24	17.20	16.12	11.29	11.93
6	No treatment—check	4.39	6.61	13.63	13.30	8.05	9.20
7	200 lbs. superphosphate, 4 tons manure	6.72	9.34	19.73	21.81	12.00	13.92
8	107 lbs. rock phosphate	5.82	9.74	15.64	17.84	8.13	11.43
9	107 lbs. rock phosphate, 4 tons manure	6.00	10.40	20.53	19.29	12.92	13.83
10	No treatment—check	6.59	8.75	16.32	18.54	10.05	12.05
	Average	5.51	7.86	14.50	16.44	9.67	....

Table 6.—Amount of nitrate nitrogen in parts per million of dry soil at different dates in 1927

Plat No.	Treatment per acre	May 18	June 18	July 18	August 18	Sept. 23	Average
		P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	6.03	5.46	2.54	2.47	6.26	4.55
2	Crop residues removed	4.21	4.79	2.44	2.41	5.63	3.90
3	No treatment—check	5.52	4.65	2.46	2.56	5.54	4.15
4	200 lbs. superphosphate	5.28	5.52	2.60	2.66	6.06	4.42
5	4 tons manure	7.70	7.10	2.77	2.70	7.62	5.58
6	No treatment—check	6.54	6.50	2.68	2.40	5.92	4.81
7	200 lbs. superphosphate, 4 tons manure	8.33	7.31	3.26	3.03	7.77	5.94
8	107 lbs. rock phosphate	7.68	6.10	2.88	2.66	7.18	5.30
9	107 lbs. rock phosphate, 4 tons manure	10.47	8.80	3.26	3.91	9.73	7.23
10	No treatment—check	8.80	9.66	3.81	3.98	7.29	6.71
	Average	7.06	6.59	2.87	2.88	6.90	....

suggested by Brown (5). These studies were made during 1926 and 1927.

Season of 1926: The soil from the plats under continuous cotton exhibited a much greater nitrifying power at each date of sampling than the soil from the plats under the other crops in 1926 (Table 7). Considering all the treatments, this soil was able to nitrify, on the average, 26.6 per cent of the nitrogen added in ammonium sulphate in four weeks, while the soil from the plats growing continuous corn, rotated cotton, rotated cowpeas, and rotated corn, converted into nitrate 11.9 per cent, 16.8 per cent, 17.9 per cent, and 20.7 per cent, respectively, of the nitrogen added.

If the effects of treatments are considered, equally striking results are noted. The soil treated with manure and superphosphate gave the highest nitrifying power for the season of 1926 when the results obtained from the soils under all the crops are averaged (Table 7). In general, the soils on Plats 5, 7, and 9, which received nitrogen, either in the form of cottonseed meal or manure, showed a more vigorous nitrifying power than the other soils. Perhaps the most striking feature of the data in Table 7 is that the soil from Plat 10, which received no treatment, showed the weakest nitrifying power with every crop. This soil, however, had a much greater accumulation of nitrates than the soils from Plats 3 and 6, which also received no treatment (Table 2). The cause of this discrepancy is not apparent from the data, although the greater hydrogen ion concentration might have been responsible (Table 12). The application of phosphoric acid, either in the form of superphosphate or rock phosphate, increased the nitrifying power to some extent but not as much as the cottonseed meal or manure.

Season of 1927: Two series of tests were made in 1927. In one series ammonium sulphate was used alone and in the other sufficient calcium carbonate was added to keep the reaction basic. The addition of lime with ammonium sulphate greatly increased the nitrifying power of the soil as compared with ammonium sulphate alone, the former producing about six and one-half times as much nitrate as the latter (Table 8). This is an interesting fact, since it was not expected that the increase would be so large. The lime appeared to reduce the variation in the nitrifying power of the soil receiving various fertilizer treatments.

The nitrogenous materials, cottonseed meal and manure, increased the nitrifying capacity of the soil. Superphosphate and rock phosphate increased slightly the power of the soil to produce nitrates, but not to the same extent as the manure and cottonseed meal. The soil under continuous corn exhibited a slightly greater nitrifying capacity than the soil under the other crops during the season of 1927.

Considering the results for the two years, it may be said that the soil treatments affected the nitrifying power to a considerable extent. In general, the soil which received nitrogen, either in the form of cottonseed meal or manure, had a greater nitrifying power and contained

Table 7.—Average amount and percentage of nitrogen in ammonium sulphate nitrified in soils under different crops, June to September, inclusive, 1926. (Thirty milligrams of nitrogen in ammonium sulphate were used, the percentage of nitrogen oxidized to nitrate being based on 30 milligrams as 100 per cent)

*Plat No.	Continuous corn		Rotated corn		Continuous cotton		Rotated cotton		Rotated cowpeas		Average	
	Mg.	%	Mg.	%	Mg.	%	Mg.	%	Mg.	%	Mg.	%
1	4.12	13.7	7.27	24.2	7.55	25.2	5.31	17.7	6.13	20.5	6.08	20.3
2	2.49	8.3	5.19	17.3	5.96	19.8	3.22	10.7	5.23	14.1	4.42	14.0
3	2.80	9.3	4.71	15.7	6.54	21.8	3.31	11.0	4.02	13.4	4.28	14.2
4	2.75	9.2	6.26	20.9	6.88	22.9	4.49	15.0	5.30	17.7	5.14	17.1
5	4.71	15.7	8.68	28.9	10.05	33.5	8.75	29.1	6.26	20.8	7.69	25.6
6	2.92	9.7	4.73	15.8	6.40	21.3	4.01	13.4	4.60	15.3	4.53	15.1
7	5.17	17.2	9.20	30.6	11.19	37.3	7.54	24.9	8.22	27.4	8.26	27.5
8	3.31	11.0	7.35	24.5	9.30	31.0	4.92	16.4	6.71	22.4	6.32	21.1
9	5.01	16.7	6.28	20.9	12.37	41.2	7.89	26.3	5.67	18.9	7.44	24.8
10	2.49	8.3	2.55	8.5	4.72	15.7	1.10	3.7	2.47	8.2	2.67	8.9
Average	3.58	11.9	6.22	20.7	8.00	26.6	5.05	16.8	5.36	17.9	5.68	18.9

*These plats have the same treatments as the plats with the corresponding numbers in Tables 1 to 6, inclusive.

Table 8.—Average nitrifying power of soil expressed as milligrams of nitrate nitrogen in 100 grams of dry soil, May to September, inclusive, 1927

Plat No.	Continuous corn		Rotated corn		Continuous cotton		Rotated cotton		Rotated cowpeas		Average	
	Ammonium sulphate		Ammonium sulphate		Ammonium sulphate		Ammonium sulphate		Ammonium sulphate		Ammonium sulphate	
	Alone	$CaCO_3$	Alone	$CaCO_3$	Alone	$CaCO_3$	Alone	$CaCO_3$	Alone	$CaCO_3$	Alone	$CaCO_3$
	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.
1	3.73	28.34	5.08	27.16	4.00	23.27	3.90	27.16	3.16	25.39	3.97	26.24
2	2.48	22.21	4.33	21.58	2.26	20.80	2.39	22.07	1.99	22.52	2.69	21.84
3	3.18	25.27	4.61	24.66	2.25	20.53	2.91	20.29	1.98	22.33	2.99	22.62
4	4.47	29.01	5.80	24.17	3.37	22.75	3.68	25.76	2.80	23.64	4.02	25.07
5	6.17	31.91	5.91	24.44	4.35	26.53	4.22	27.87	4.25	29.08	4.98	27.97
6	2.78	23.51	4.72	23.69	2.65	19.19	2.94	23.90	2.35	21.02	3.09	22.26
7	5.08	34.98	5.98	25.06	4.10	24.51	5.10	28.35	4.59	28.05	4.97	28.19
8	3.87	30.67	4.30	25.01	2.65	21.53	4.59	26.47	3.22	25.52	3.73	25.84
9	5.99	34.07	4.34	23.36	4.36	23.60	4.25	27.16	2.99	24.44	4.39	26.52
10	2.99	28.68	1.90	21.96	1.93	19.04	2.62	19.05	1.93	11.27	2.27	20.00
Average	4.48	28.87	4.70	24.11	3.19	22.18	3.66	24.81	2.93	23.33	3.79	24.66

more nitrates than the soil receiving other treatments. The soil treated with 4 tons of manure and 200 pounds of superphosphate showed a more vigorous nitrifying power than the soil which received other treatments.

The soil under rotated corn had a greater nitrifying power than the soil under continuous corn. On the other hand, in 1926 the soil under continuous cotton had a much greater capacity to produce nitrates than the soil under the other crops. These facts seem to indicate that cotton may be grown continuously on this particular soil with less reduction in yield than corn. This apparently is confirmed by published data on the yields of crops on the plats used in these studies over a period of 14 years, in which it is shown that the yield of continuous corn declined more than the yield of continuous cotton (Texas Agricultural Experiment Station Bulletin 390, 1928).

Correlation of Nitrifying Power with Yield of Crops: The preceding discussion considered the nitrifying power of the soil in relation to the various treatments. It is desirable at this point to show briefly the relationship between the nitrifying capacity of the soil and the yield of cotton and corn. Accordingly, coefficients of correlation were computed to show this relationship. The correlation coefficient between the yield of continuous cotton and the nitrifying power of the soil was .746 ±.095 in 1926 and .789 ±.081 in 1927, both of which are significant (Table 13). The correlation between the yield of rotated cotton and the nitrifying capacity of the soil was significant in both years, being .833 ±.065 in 1926 and .829 ±.067 in 1927.

Significant positive correlation was found between the yield of continuous corn and the average nitrifying power of the soil, the coefficient being .742 ±.096 in 1926 and .658 ±.121 in 1927 (Table 14). For corn grown in rotation the coefficient of correlation was .576 ±.143 in 1926 and .192 ±.206 in 1927.

The correlations obtained with corn indicate that the yield of corn is more closely correlated with the nitrifying capacity of the soil than with the amount of nitrates in the soil under the growing crop.

CHEMICAL STUDIES

The chemical studies included analyses for total nitrogen, active phosphoric acid, total phosphoric acid, and hydrogen ion concentration.[1]

Total Nitrogen

It will be observed that the soil which received nitrogen, either in the form of cottonseed meal or farm manure, contained, as a rule, slightly more nitrogen than the soil which received no nitrogenous manures (Table 9). For instance, Plat 1, which received annually 200

[1]The author is indebted to Dr. G. S. Fraps, Chief of the Division of Chemistry, Texas Agricultural Experiment Station, for determinations of total nitrogen in 1926, of active phosphoric acid in 1925 and 1926, and of total phosphoric acid in 1926.

Table 9.—Percentage of nitrogen in samples of soil collected under crops in May, 1926, and May, 1927

Plat No.	Treatment per acre	Continuous corn		Rotated corn		Continuous cotton		Rotated cotton		Rotated cowpeas	
		1926	1927	1926	1927	1926	1927	1926	1927	1926	1927
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	.043	.040	.055	.048	.045	.042	.050	.047	.050	.049
2	Crop residues removed	.046	.043	.050	.042	.041	.038	.049	.044	.045	.048
3	No treatment—check	.045	.042	.047	.039	.042	.039	.048	.051	.042	.044
4	200 lbs. superphosphate	.055	.051	.046	.045	.044	.041	.048	.044	.048	.042
5	4 tons manure	.057	.053	.056	.049	.049	.046	.057	.047	.052	.040
6	No treatment—check	.045	.042	.052	.038	.056	.052	.050	.045	.041	.049
7	200 lbs. superphosphate, 4 tons manure	.065	.061	.055	.055	.065	.061	.055	.051	.059	.058
8	107 lbs. rock phosphate	.057	.053	.047	.053	.059	.055	.054	.056	.057	.053
9	107 lbs. rock phosphate, 4 tons manure	.066	.062	.053	.052	.058	.054	.057	.051	.056	.050
10	No treatment—check	.060	.056	.051	.051	.051	.048	.046	.044	.054	.048

Table 10.—Active phosphoric acid in parts per million of dry soil in samples collected under the crops in May, 1925, and May, 1926

Plat No.	Treatment per acre	Continuous corn		Rotated corn		Continuous cotton		Rotated cotton		Rotated cowpeas	
		1925	1926	1925	1926	1925	1926	1925	1926	1925	1926
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	146	118	144	123	120	99	139	79	106	127
2	Crop residues removed	44	33	48	36	22	117	46	102	38	43
3	No treatment—check	38	37	33	31	36	40	39	39	33	45
4	200 lbs. superphosphate	135	115	91	120	129	134	113	109	116	112
5	4 tons manure	78	74	46	59	62	68	84	64	47	63
6	No treatment—check	34	32	36	64	30	31	36	30	44	35
7	200 lbs. superphosphate, 4 tons manure	135	112	93	140	136	157	85	113	117	116
8	107 lbs. rock phosphate	124	125	181	108	94	114	105	139	166	120
9	107 lbs. rock phosphate, 4 tons manure	....	137	144	111	150	162	118	119	116	117
10	No treatment—check	....	67	58	58	107	90	62	48	67	54

pounds of superphosphate and 100 pounds of cottonseed meal per acre, contained more nitrogen than either Plat 2, which had the crop residues removed yearly since 1913, or Plat 3, which received no treatment of any kind. Plats 5, 7, and 9, which received 4 tons of manure with or without phosphoric acid, had more nitrogen than the nearest untreated check plats. These data also show that the percentage of nitrogen increased progressively from Plat 3 to Plat 10, when all the plats on the five blocks are considered.

The percentage of total nitrogen was positively correlated with the amount of nitrates in the soil under the growing crops and with the nitrifying power of the soil, as shown in Tables 13 and 14. The correlation, however, was not significant in all cases.

Active Phosphoric Acid

In most cases the addition of phosphoric acid in the form of superphosphate or ground rock phosphate increased the amount of active phosphoric acid in the soil (Table 10). The soil receiving rock phosphate contained as much active phosphoric acid as the soil receiving equal amounts of phosphoric acid in the form of superphosphate. These two forms of phosphoric acid have been equally effective in increasing the yield of cotton and corn (Texas Agricultural Experiment Station Bulletin 390). The kind of crop or the season appeared to have no consistent effect on the amount of active phosphoric acid.

While the amount of active phosphoric acid in the soil was closely associated with the application of phosphatic fertilizers, there was no significant correlation between the amount of active phosphoric acid and the yield of cotton (Table 13) or the yield of corn (Table 14). The yield of cotton in 1926, however, was correlated to some extent with the active phosphoric acid, the coefficient of correlation being .447 $\pm$.171 and .426 $\pm$.175 for continuous cotton and cotton grown in rotation, respectively.

Significant positive correlation was found between the active phosphoric acid and the average nitrifying power of the soil under continuous cotton, under continuous corn, and under rotated corn in 1926. The coefficient of correlation was .557 $\pm$.147 for continuous cotton (Table 13), .584 $\pm$.141 for continuous corn, and .603 $\pm$.136 for rotated corn (Table 14).

Total Phosphoric Acid

The Lufkin fine sandy loam soil used in the experiment is low in phosphoric acid, as shown in Table 11. The addition of phosphatic fertilizers, however, has increased to some extent the percentage of phosphoric acid in the soil. For example, the soil on Plats 1, 4, 7, 8, and 9, which have received phosphoric acid in the form of superphosphate or ground rock phosphate, contained more phosphoric acid, as a rule, than the soil on Plats 3, 6, and 10, which have received no fertilizer treatment of any kind since 1914.

The total phosphoric acid in the soil was significantly correlated with

Table 11.—Percentage of total phosphoric acid in samples of soil collected in May, 1926, and May, 1927

Plat No.	Treatment per acre	Continuous corn		Rotated corn		Continuous cotton		Rotated cotton		Rotated cowpeas	
		1926	1927	1926	1927	1926	1927	1926	1927	1926	1927
1	200 lbs. superphosphate, 100 lbs. cottonseed meal	.028	.033	.016	.036	.034	.034	.026	.032	.029	.033
2	Crop residues removed	.024	.018	.019	.019	.024	.017	.024	.019	.034	.020
3	No treatment—check	.020	.018	.019	.021	.029	.015	.016	.023	.026	.019
4	200 lbs. superphosphate	.031	.029	.034	.030	.038	.036	.026	.034	....	.030
5	4 tons manure	.028	.027	.021	.026	.033	.022	.020	.023	.028	.024
6	No treatment—check	.027	.017	.024	.024	.029	.017	.013	.024	.022	.024
7	200 lbs. superphosphate, 4 tons manure	.033	.025	.033	.029	.031	.031	.033	.029	.034	.031
8	107 lbs. rock phosphate	.033	.032	.042	.027	.027	.029	.038	.038	.032	.031
9	107 lbs. rock phosphate, 4 tons manure	.030	.037	.032	.034	.034	.034	.038	.028	.029	.032
10	No treatment—check	.025	.021	.025	.021	.023	.024	.026	.023	.024	.021

the yield of continuous cotton in 1927, the coefficient of correlation being .645 ±.125, as shown in Table 13. In 1926, however, the correlation was not significant. The amount of phosphoric acid was significantly correlated with the average nitrifying power of the soil under continuous cotton and under cotton grown in rotation in 1927 (Table 13) and under continuous corn in 1926 and 1927 (Table 14).

Hydrogen Ion Concentration

The hydrogen ion concentration (pH value) of the soil was determined by the colorimetric method, using La Motte indicators to develop the color. *In this work the ratio of soil to water was 1 to 5.* Twenty grams of soil were weighed out, placed in Erlenmeyer flasks, and 100 cc. of distilled water having a pH of 6.6 to 6.8 was added. The flasks were then shaken vigorously, stoppered, and the soil allowed to settle over night. Usually perfectly clear solutions were obtained in this manner.

Table 12.—Hydrogen ion concentration (pH value) of soil samples collected under the crops May 18, 1927

Plat No.	Treatment per acre	Continuous corn	Rotated corn	Continuous cotton	Rotated cotton	Rotated cowpeas
		pH	pH	pH	pH	pH
1	200 lbs. superphosphate, 100 lbs. cottonseed meal.	6.5	6.3	6.5	6.5	6.4
2	Crop residues removed....	6.5	6.5	6.6	6.6	6.4
3	No treatment—check.....	6.5	6.6	6.4	6.6	6.4
4	200 lbs. superphosphate...	6.5	6.6	6.5	6.5	6.5
5	4 tons manure...........	6.5	6.3	6.6	6.5	6.5
6	No treatment—check.....	6.3	6.3	6.6	6.5	6.5
7	200 lbs. superphosphate, 4 tons manure.........	6.4	6.4	6.4	6.4	6.4
8	107 lbs. rock phosphate...	6.4	6.2	6.3	6.4	6.4
9	107 lbs. rock phosphate, 4 tons manure..........	6.4	6.0	6.5	6.5	6.2
10	No treatment—check.....	6.2	6.0	6.2	6.4	6.2

The pH values were determined on samples taken from the various plats in May, June, July, and August, 1927. Since the results obtained during each of the four months were quite similar, only the pH values of the samples taken in May are given here (Table 12). The highest pH value in May was 6.6 and the lowest pH value was 6.0, which occurred on Plats 9 and 10 of rotated corn. In general the soil on Plat 10 of each of the blocks had a low nitrifying power in 1926 and 1927 (Tables 7 and 8), which may possibly have been due to the greater hydrogen ion concentration.

Apparently the fertilizer treatments used had no consistent or appreciable effect on the hydrogen ion concentration of the soil. These results, in general, agree with the work of other investigators.

STATISTICAL ANALYSIS OF THE DATA

While the relation of the various chemical and microbiological factors among themselves and their bearing on the yield of crops may be shown by graphs and curves, it is believed that these relationships can be shown better by the use of statistical methods. Accordingly, the coefficient of correlation existing between the several pairs of factors studied was calculated. In this connection it may be pointed out that the literature does not contain much data on the statistical analysis of the chemical and microbiological factors of soil fertility and the relation of these factors among themselves and to the yield of crops. Recently, however, McCall and Wanser (16) in a study of summer fallow tillage in Washington used the statistical method in the interpretation of their data. They found significant positive correlation between the amount of nitrates in the soil and the yield of wheat, between the moisture content of the soil and the yield of wheat, and between the amount of nitrates in the soil and the protein content (quality) of wheat.

As mentioned previously, data were secured on (a) the amount of nitrates in the soil under the growing crops, (b) the nitrifying power of the soil, (c) the total nitrogen, (d) the total phosphoric acid, (e) the active phosphoric acid, and (f) the hydrogen ion concentration (pH value) of the soil. Coefficients of correlation between the several pairs of factors were computed according to the method of Wallace and Snedecor[2] for machine calculation.

The correlation coefficients reported are based on only ten observations for each pair of characters, since there were but ten plats of each crop grown. While significant correlations have been obtained in many cases, they should be regarded as indicating the probability rather than the certainty of the relationship of the several characters on account of the small numbers involved. The data have been analyzed with these limitations in mind.

Correlation Data Obtained on Cotton

The yield of cotton was positively correlated with the nitrate content, with the nitrifying power, with the total nitrogen, and with the total and active phosphoric acid of the soil (Table 13). The coefficient of correlation between the yield of continuous cotton and the amount of nitrates in the soil under the crop in May was .646 ±.124 in 1926 and .706 ±.107 in 1927, both of which are significant. Positive correlation also was found between the yield of continuous cotton and the average amount of nitrates in the soil during the season, the correlation being .552 ±.155 in 1926 and .700 ±.109 in 1927. The average nitrifying power of the soil during the season apparently was a better index of the productiveness of the soil than the other factors studied. For example, the coefficient of correlation between the yield of continuous cotton and the average nitrifying power of the soil was .746 ±.095 in 1926 and .789 ±.081 in 1927. In the case of cotton grown in rotation the coefficient of correlation was .833 ±.065 in 1926 and .829 ±.067 in 1927.

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[2]H. A. Wallace and George W. Snedecor, "Correlation and Machine Calculation," Iowa State College, Ames, Iowa, 1925.

While the yield of cotton was positively correlated with the total amount of nitrogen, with the total phosphoric acid, and with the active phosphoric acid of the soil, in most cases the correlation was not significant (Table 13).

Table 13.—Coefficients of correlation between chemical and microbiological factors and yield of cotton

Pairs of characters	Continuous cotton		Rotated cotton	
	1926	1927	1926	1927
Yield and nitrates in May	.646 ±.124	.706 ±.107	.415 ±.177	.600 ±.137
Yield and average amount of nitrates	.552 ±.155	.700 ±.109	.491 ±.162	.389 ±.181
Yield and nitrifying power in May	.665 ±.123	.702 ±.108	.875 ±.050	.654 ±.122
Yield and average nitrifying power	.746 ±.095	.789 ±.081	.833 ±.065	.829 ±.067
Yield and total P_2O_5	.416 ±.177	.645 ±.125	.417 ±.177	.346 ±.188
Yield and total N	.444 ±.171	.639 ±.126	.776 ±.085	.446 ±.171
Yield and active P_2O_5	.447 ±.171	....	.426 ±.175	....
Total N and average amount of nitrates	.841 ±.063	.926 ±.302	.405 ±.178	.148 ±.167
Total N and nitrifying power in May	.382 ±.182	.221 ±.203	.667 ±.119	.134 ±.210
Total N and average nitrifying power	.641 ±.126	.347 ±.188	.789 ±.080	.184 ±.206
Average nitrifying power and total P_2O_5	.476 ±.165	.602 ±.136	.361 ±.186	.795 ±.079
Average nitrifying power and active P_2O_5	.557 ±.147	....	.395 ±.180	....

The total nitrogen in the soil was positively correlated with the amount of nitrate nitrogen in the soil and with the nitrifying capacity of the soil. The correlation between the amount of total nitrogen in the soil under continuous cotton and the average quantity of nitrates in the soil during the season was .841 ±.063 in 1926 and .926 ±.302 in 1927.

The nitrifying power of the soil was correlated with the total amount of phosphoric acid and the active phosphoric acid although the correlation was not significant in all cases (Table 13).

Correlation Data Obtained on Corn

The yield of corn was correlated with the average nitrifying power of the soil, as shown in Table 14. In the case of corn grown on the same land every year the coefficient of correlation was significant, being .742 ±.096 in 1926, and .658 ±.121 in 1927. The yield of corn grown in rotation in 1927, however, was not correlated with the nitrifying power of the soil, either in May or with the average of the season.

The total nitrogen, the total phosphoric acid, and the active phosphoric acid were not significantly correlated with the yield of either continuous or rotated corn. The percentage of total nitrogen was positively and significantly correlated with the average amount of nitrates in the soil, except in the case of rotated corn in 1926 (Table 14).

The coefficient of correlation between the average nitrifying capacity and the amount of nitrogen in the soil under continuous corn was .591 ±.139 in 1926 and .694 ±.111 in 1927. In the case of rotated corn, the coefficient of correlation probably was not significant in 1926 or in 1927. Significant positive correlation was found between the nitrifying power and the total phosphoric acid in the soil under continuous corn but no such relation was found to exist in the soil under rotated corn. The active phosphoric acid also was significantly correlated with the nitrifying power of the soil under both rotated corn and continuous corn in 1926, the coefficient of correlation being .603 ±.136 and .584 ±.141, respectively.

Table 14.—Coefficients of correlation between chemical and microbiological factors and yield of corn

Pairs of characters	Continuous corn		Rotated corn	
	1926	1927	1926	1927
Yield and nitrates in May..........	.280 ±.197	.149 ±.209	-.504 ±.159	-.741 ±.096
Yield and average amount of nitrates.	.051 ±.213	-.026 ±.213	-.313 ±.192	-.781 ±.083
Yield and nitrifying power in May...	.322 ±.191	.386 ±.182	.797 ±.078	.042 ±.213
Yield and average nitrifying power...	.742 ±.096	.658 ±.121	.576 ±.143	.192 ±.206
Yield and total P_2O_5...............	.209 ±.204	.201 ±.205	-.393 ±.182	-.284 ±.196
Yield and total N..................	.229 ±.202	.122 ±.204	.347 ±.188	-.469 ±.166
Yield and active P_2O_5..............	.147 ±.209	....	.188 ±.206	....
Total N and average amount of nitrates....................	.981 ±.008	.926 ±.030	.362 ±.185	.524 ±.155
Total N and nitrifying power in May.	.844 ±.041	.904 ±.038	.416 ±.170	-.167 ±.154
Total N and average nitrifying power.	.591 ±.139	.694 ±.111	.488 ±.163	-.355 ±.187
Average nitrifying power and total P_2O_5....................	.545 ±.150	.653 ±.123	.099 ±.211	.418 ±.176
Average nitrifying power and active P_2O_5....................	.584 ±.141	....	.603 ±.136	....

DISCUSSION OF RESULTS

The kind of crop and cropping system had distinct effects on the accumulation of nitrates in the field soil. The soil under rotated cotton contained the largest amount of nitrates during the seasons of 1925 and 1927, but the soil under rotated corn contained the largest average amount for the three years, which was due to the greater accumulation of the nitrates in the soil in August and September, 1926, after the corn had matured and ceased taking up nitrates. The soil under continuous cotton and under continuous corn contained significantly smaller quantities of nitrates than the soil under cotton and corn grown in rotation. This fact indicates that the growing of cotton or corn on the same land every year has a depressing, or injurious, effect on the accumulation of nitrates in the soil.

Nitrate production, or accumulation of nitrates, in field soil under cotton gradually increased as the season advanced, reaching a peak in July and decreasing thereafter. It followed a similar course in the soil under corn, except the greatest accumulation occurred a month later, in August. The greater accumulation under corn apparently was due to the fact that the corn having matured ceased absorbing nitrates during the latter part of July and conditions during August were favorable for nitrification, conditions which were conducive to the accumulation of nitrates.

The season, that is, the date of sampling, apparently had no consistent influence on the nitrifying power of the soil under laboratory conditions. The growing of corn on the same land every year, however, had a tendency to lessen the power of the soil to produce nitrates, since the soil under continuous corn did not nitrify ammonium sulphate as rapidly as the soil under the other crops. This fact apparently explains why the yield of corn is reduced more by continuous cropping than is the yield of cotton.

The application of nitrogen, in the form of cottonseed meal and manure, and of phosphoric acid, as superphosphate or ground rock phosphate, increased the production of nitrates in the field soil and stimulated the nitrifying power of the soil. In fact, the treatment of 200 pounds of superphosphate and 4 tons of manure per acre brought about the greatest accumulation of nitrates in the field and the most vigorous nitrifying capacity of the soil in the laboratory. These results are in general agreement with those of other workers.

In studying the nitrifying power of the soil, ammonium sulphate was used as the source of nitrogen. In one series the ammonium sulphate was used alone and in another with lime to keep the reaction basic. Lime increased the nitrifying capacity of the soil, since the soil which received lime produced about six times as much nitrate nitrogen as the soil which received no lime. These results are similar to the results reported by Erdman and Humfeld (Iowa Agricultural Experiment Station Research Bulletin 110, 1928).

The use of the statistical method in the interpretation of the data revealed some interesting results and indicated certain relationships that were not apparent before the correlations were made. The yield of cotton was significantly correlated with the amount of nitrates in the soil under the growing crop and with the nitrifying power of the soil. The nitrifying capacity of the soil was a better single index of the productiveness of the soil than the other factors studied. These results are in accord with those of Brown (5, 6, 7, 8), Burgess (9), Gainey and Gibbs (11), and Waksman (22). Regarding nitrification as an indicator of productiveness, Burgess (9) stated, "In fact it is probably the best single test of any description yet developed for ascertaining the comparative crop-producing power of arable soils."

The yield of cotton was positively correlated with the total nitrogen, with the total phosphoric acid, and with the active phosphoric acid of the soil, but in most cases the correlation was not significant. The nitrifying power of the soil was correlated with the total and active phosphoric acid, although the correlation was not significant in all cases.

In general the results obtained with cotton were better indicators of productiveness of the soil than the results obtained with corn.

Statistical methods have not been used extensively in the interpretation of soil fertility and soil microbiological data, especially the relation of these factors to the yield of crops. It is believed, however, from the results reported in this Bulletin, that a more extensive use of statistical methods is justified, since they are valuable in the interpretation of data and often permit of more definite conclusions than would otherwise be secured.

SUMMARY

In a chemical and microbiological study of Lufkin fine sandy loam soil in 1925, 1926, and 1927 at the Texas Agricultural Experiment Station, College Station, Texas, the nitrifying power of the soil was correlated positively and significantly with the yields of cotton and corn. The nitrifying capacity of the soil was a better index of the productiveness of the soil than any other factor studied. The nitrifying power of the soil was also positively correlated with the total nitrogen, with the total phosphoric acid, and with the active phosphoric acid of the soil.

The nitrifying capacity of the soil in the laboratory was not affected by the season, as indicated by the analyses of samples taken at different times during the growing season. The growing of corn on the same land every year had a tendency to weaken the nitrifying capacity of the soil.

The application of nitrogenous materials, cottonseed meal and manure, and of phosphoric acid, as superphosphate or ground rock phosphate, increased the production of nitrates in field soil and stimulated the nitrifying power of the soil. Under conditions in the laboratory the addition of lime increased the capacity of the soil to produce nitrates, since the soil that received lime produced about six times as much nitrates as the soil that received no lime. This increased nitrifying power, however, was not more significantly correlated with the yield of cotton and corn than was the nitrifying power of the soil without lime.

The continuous growing of cotton and of corn decreased the production of nitrates in field soil.

The accumulation of nitrates in the soil gradually increased as the season advanced, reaching a peak in July in the soil under cotton and in August in the soil under corn, and decreasing thereafter.

The results obtained with the statistical method in this study indicate that the method could be used more extensively than it is at present, since its use permits of more definite conclusions than would be obtained otherwise.

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